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A RECONSTRUCTION OF THE SKULL OF *GIGANTOPITHECUS BLACKI* AND ITS COMPARISON WITH A LIVING FORM

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ABSTRACT: A skull of *Gigantopithecus blacki* has been constructed by the author based on the adult male jaw from China. This presumes erect, bipedal locomotion for the original, and an ape-sized brain scaled to the appropriate body size. The final product is far larger than a male gorilla, and compares favorably with reports of the unverified North American Sasquatch (Bigfoot).

INTRODUCTION

The largest known primate, *Gigantopithecus blacki,* lived in southern China somewhere between a half and one million years ago. It is known from the tooth-bearing parts of three lower jaws and over a thousand loose teeth. Dental traits clearly show it to be hominoid (in the superfamily of apes and humans), but authoritative opinion is divided as to whether or not it should be classified within the human family, Hominidae.

Upright, bipedal locomotion is the ultimate criterion for inclusion in the human family, as opposed to that of the great apes, Pongidae. Weidenreich (1946) and Eckhardt (1972) classed *Gigantopithecus* as a hominid, and proposed it as an actual human ancestor, but were vague on the point of bipedalism. Wu (1962) and Robinson (1972: 6) made the species hominid and bipedal, but on a separate line from ourselves, and presumably extinct.

As far back as the early 1950's, Heuvelmans (1952) suggested, on the basis of the few teeth then known, that *Gigantopithecus* might be the direct ancestor of the reported Himalayan Yeti. Later, Sanderson (1961) and Coon (1962: 207) also speculated on its possible relationship to the Yeti.

In 1968, Green made the connection with the North American Sasquatch, or Bigfoot. More recently, I formally proposed to equate the two species under *G. blacki,* but expressed the hope that *G. canadensis* would become the accepted name if the Sasquatch proved to be a separate species (Krantz 1986). I also suggested using the name *Gigantanthropus canadensis* if it should prove to be generically distinct, or *Australopithecus canadensis* if future discoveries should point in that direction. However, such proposals carry no legal weight under the established rules of zoological nomenclature.

All of these ideas presently suffer from the fact that there is no direct overlapping of evidence between the known fossils and the reported living species. We have no footprints or eyewitness accounts of the Chinese fossil

animals; we have no skeletal remains of the North American Sasquatch, or of any other unverified hominoid.

Pilbeam *et al.* (1980) allowed about 100 kg body weight for the possibly related fossil jaw from India. Simons and Ettel (1970) assumed all gigantopithecines were knuckle-walkers. Helmut Hemmer (personal communication, 1985) questioned our ability to make any predictions of body size or locomotion from dentition. If all or any of these opinions are correct, we have little reason to seriously equate *Gigantopithecus* with the Sasquatch, or with any other of the reported unknown hominoids.

Contrary to the common view, I think a great deal can be determined about body size and locomotion from dentition alone. This depends on correctly identifying the type of teeth and how they were used. But with *Gigantopithecus* we also have much of the jaw itself, thus greatly improving our predictive ability from that based on teeth alone.

With some tooth-to-jaw ratios in hand, it should not be difficult to reconstruct the entire mandible. Extant upper teeth can be fitted, with supporting bone, to restore much of the upper jaw directly. The necessary muscle crests and other supporting structures follow almost automatically. Given the great divergence of the jaw, as well as the reduced sectorial complex in the teeth, an erect posture may be deduced (Krantz 1981). This tells us how to orient the muscle crests at the base of the skull. The overlap of *Gigantopithecus* with early *Homo* allows us to eliminate the former from consideration for cultural behavior, and thus predict ape-like cognitive abilities. Scaling up from the chimpanzee at 400 cc of braincase volume to the gorilla at 500 cc, one can reasonably assign 600 cc to this fossil form. A full reconstruction of the skull thus should offer no serious problem. Such a reconstruction would give strong indications of the total body size and general appearance of these animals in life. And this, in turn, might allow for some more direct and perhaps meaningful comparisons with the reported living form.

THE RECONSTRUCTION

Having made the above observations many times, I have been urged repeatedly to put my hands where my mouth is, and actually produce this reconstruction. During the autumn of 1985 I made the mandible, and in the spring of 1986 the rest of the skull was completed. What follows is a description of the more detailed reasoning and procedures that were employed in this work.

I began by moving the right third molar laterally from its obviously disturbed position to line up the tooth row like the undistorted left side. The right second molar and the two medial incisors were added, and a few surface irregularities were filled in. None of this required any serious judgment, much less reconstructive imagination.

The first step was to establish the most likely breadth of the ascending ramus of the mandible. Simply stated, this means extending a line along the lower tooth row beyond the last molar to where it meets the upright, rear edge of the jaw. I measured the actual breadth of this ascending ramus, at the level of the tooth row, in my available sample of hominid and pongid jaws. This measurement was then laid out along the length of the tooth row in each specimen, from the back of the last molar, to see how far forward it went.

The most common result was that the ramus breadth equaled the distance from the end of the tooth row to the middle of the anterior premolar. This was true for such specimens as the Upper Cave Zhoukoudian male, the La Ferrassie Neanderthal, one robust australopithecine, a male gorilla, and a male orang-utan. The Heidelberg jaw had a greater ramus breadth, equal to a line running just onto its canine. Other jaws had slightly narrower rami, such as Cro-Magnon, Skhul V, male "Sinanthropus," three robust australopithecines, and a female orang-utan.

Since the existing part of the *Gigantopithecus* jaw shows excessive height and thickness relative to its teeth, I assumed that its length (ramus breadth) might lean in this same direction. Accordingly, I chose the slightly above-average measurement basis of mid-anterior premolar to last molar. This was 88 mm—well above the largest of my comparative samples (75 mm in a male gorilla), and twice the average for specimens within the genus *Homo.*

The front edge of the ascending ramus, the coronoid process, is preserved in its lowest part on each side. Since this edge runs almost straight up (perpendicular to the occlusal plane of the teeth), it provided the anterior edge of the 88 mm wide ramus (Fig. 1).

The two rami are set far apart and continue to diverge strongly toward the back. This divergence follows the approximate trend of the molar-premolar row, and also the direction of the lower edge of the mandibular body. It is normal in most primates—and in all specimens in my hominoid sample—for the jaw to continue this divergence in a nearly straight line along each side (Fig. 2).

Reconstructing the height of the ascending ramus followed a similar procedure. The total ramus heights to the condyles were measured perpendicular to the surface on which the sample jaws rested. The heights from the crowns of the third molars to the same resting surface were then measured. (I measured from the center of the molar crown to neutralize most wear differences.) Seven *Homo* specimens clustered tightly around the mean of ramus height, being 1.64 times M3 + body height. Four robust australopithecines clustered tightly around 2.0 times taller. Three apes ranged widely around 2.08 times taller.

I made the *Gigantopithecus* ramus exactly 1.96 times taller (199 mm); I was aiming for 2.0 times, but the clay slumped slightly. This height also followed from trying to visualize the condyle's vertical position in order to

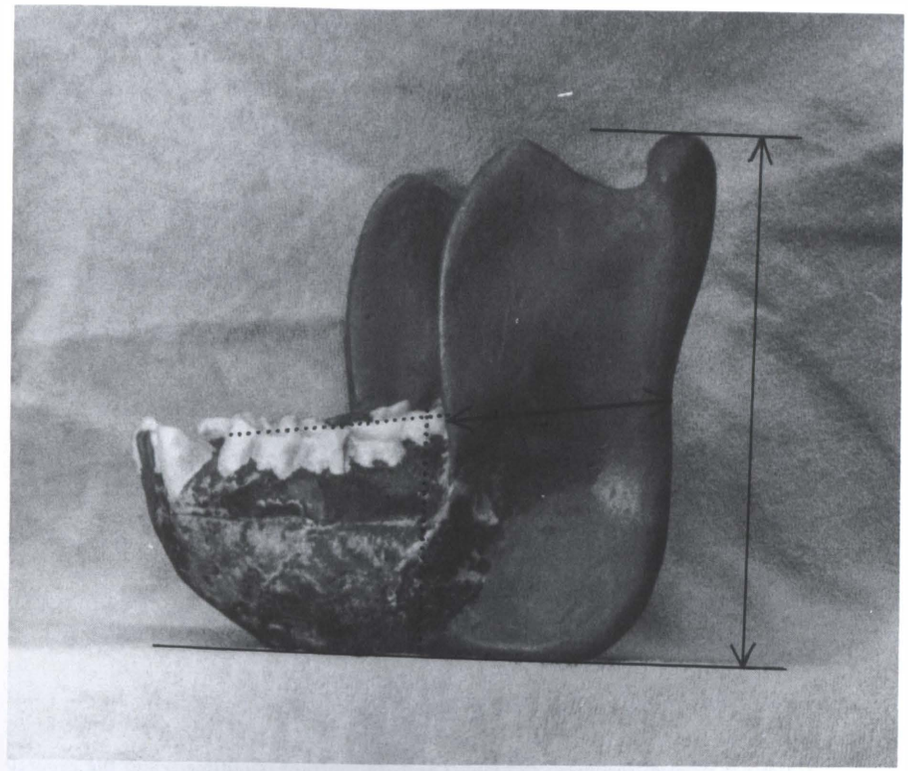

FIG. 1.—Side view of reconstructed jaw, with flat surface to camera. The 88-mm breadth of the ascending ramus (rear, rising part) is based on the length along the tooth row shown in dotted line. The 199-mm height of the ascending ramus, from resting surface, is twice the height at the third molar, shown as another dotted line.

give the jaw the motions that would produce the observed tooth wear. Here, the cuspal interlocking is well worn away by an anterior migration of the lower jaw. This requires a highly placed condyle, well above the occlusal plane, so that the jaw moved forward as well as upward as the tooth crowns eroded in life (see Fig. 1).

After settling on the breadth and height of the ascending ramus, I was able to model the details with typical hominid contours. There were some guides in the extant fossil jaw. The divergence of the body of the mandible was continued to the rear corners (gonia), then thickened with a slight outward flare as in normal hominoid jaws. This gave an excessive breadth, but any attempt to narrow it would have produced an unusual shape with no justification.

The leading edge of the ascending ramus (coronoid process) is preserved enough to show it also has a strong outward flare. This obliged me to re-

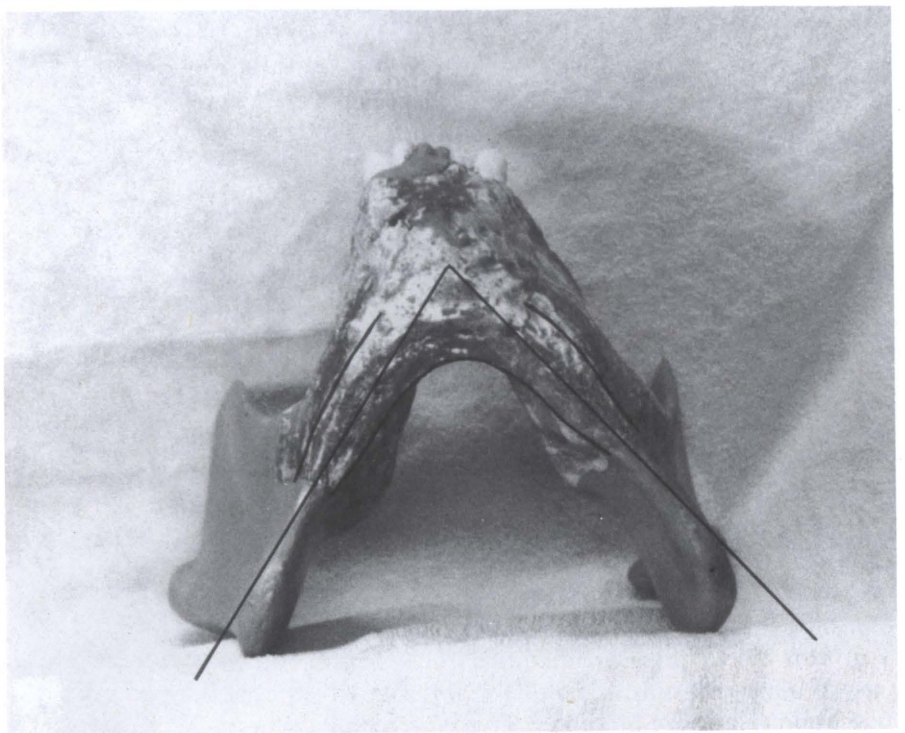

FIG. 2.—Bottom view of reconstructed jaw. The basal portion is outlined, and the general trend of divergence is drawn in as straight lines. These spread at 76°, while an earlier reconstruction by the author put this at 84° by concentrating more on the lowermost edge. The posterior parts follow this trend but are inflected slightly at the corners.

construct a considerable concavity in the lateral surface of the ramus. This implies a very powerful masseter muscle, and, in turn, very strong zygomatic arches (cheek bones) above, where the masseter originates.

The size of the condyle is proportional to the jaw. Its shape, and the entire outline of the ramus as well, follows a generalized hominid/hominoid design. Relative thickness of the reconstructed bone is greater than is usual in primates. This is an allometric effect, as relative thickness increases with absolute size in extant forms, so this is simply extrapolated a considerable step beyond the gorilla.

In all this, as well as other parts of the skull, I first made numerous drawings and partial restorations showing the new parts both larger and smaller than what was ultimately decided on. Each of these extremes was then studied in order to determine if the implied anatomical relationships were unworkable, inefficient, or wasteful of biological material. After bracketing with too large—too small, too wide—too narrow, too tall—too short, etc., I was able

to close in on what appeared to be the most likely size and/or shape. This involved placing all muscles, locating all levers, judging all moving masses, and so on, for all normal as well as abnormal movements of these parts.

I would not be so bold as to suggest this procedure was perfect and yielded exact results, but it is not likely that any serious error could have been introduced. Of course, only the finding of an actual *Gigantopithecus* skull will serve to check its accuracy.

This mandible might now be compared with the earlier reconstruction by Wu Rukang (1962). Our differences are only of degree. Wu made the ramus somewhat less tall, but prolonged it backward much more than I did. He seems to have tried to turn the sides inward slightly to avoid some of the indicated divergence, and thereby give it a more "normal" appearance. By giving it such length, however, his jaw is actually wider at the back than mine is. Overall, Wu's reconstruction is somewhat the larger and more ape-like. A more serious comparison of actual measurements is saved for later in this paper, but it is fair to say at this point that a 500-kg body size is quite possible.

The upper dentition is based on Wu's description of the recovered teeth. These fall into two size categories, the larger of which correspond to those in the mandible and are presumed to be of males. Average measurements of these larger teeth were laid out in an arch that would normally occlude with those in the lower jaw. This involves having the upper teeth overlap outside the lowers around most of the arch, but close in to meet just about crown-to-crown at the third molars. The observed wear pattern and its slopes follow from this occlusion, which is also true for almost all primates.

In constructing this upper dental arcade, I was unable to fit in teeth of average male size, but had to reduce them slightly. This implies that this individual was somewhat below average size—at least in its dentition.

The alveolar (tooth-supporting) part of the upper jaw was made relatively thick, corresponding to its thickness in the lower jaw. The hard palate was placed at a medium height, typical of early hominids. This may not be correct, but minor variations in this have little repercussion on any other traits. (The reader might note that the restorations are based on hominoids when apes and humans are the same, and on hominids when there is a difference.)

Recovered upper canines have long roots (45 mm). This would place their supporting alveolar bone well above the lower edge of the nasal aperture. The distance between the upper canines thus strongly influences the breadth of the nasal aperture (Coon with Hunt 1965: 250). The spacing between these canines can be determined from the sizes of the four incisors that form an arc between them, and by the positions of the lower canines which the uppers should partially overlap. These two methods agree in placing the canine roots' medial edges about 30 mm apart at the gum line, and spreading

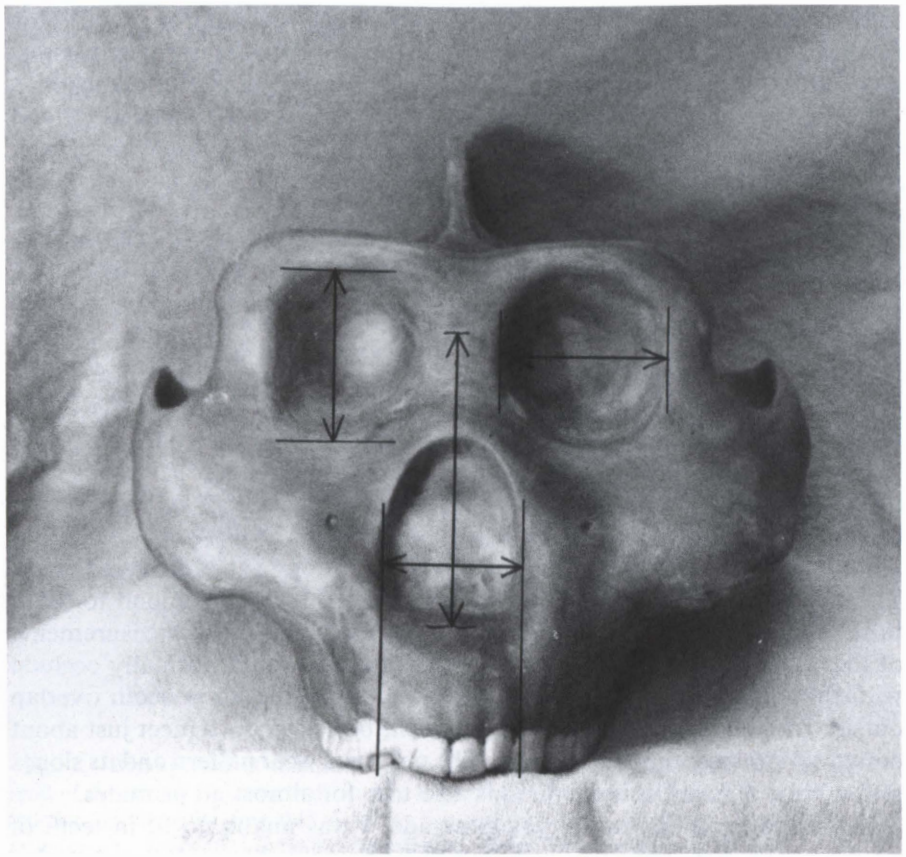

FIG. 3.—Front view of reconstructed cranium. The 50-mm nasal breadth lines up with the spacing between the canine tips. The 115-mm height of the nasal chamber is slightly arbitrary at the top, but corresponds well with the great height of the mandible. Orbit diameters of 65 mm are also indicated.

to at least 50 mm at their tips. This allows a lower breadth of nasal aperture also of about 50 mm, and higher up it can have little or no greater breadth (Fig. 3).

The height of the entire nasal chamber can be roughly deduced from its breadth and from the total body size. The volume of inspired air must be proportional to the body's needs. With a nasal chamber breadth somewhat more than that of a male gorilla, and an all-over body at least twice as great, the same level of activity can be maintained with a chamber half-again taller. This kind of nasal height (115 mm vs. 88 mm in the gorilla) was introduced into the reconstruction, and was found to fit nicely with the high placement of the mandibular condyles. This internal cross-checking was gratifying (see Fig. 3).

FIG. 4.—Top view of reconstructed cranium. The 30-mm flange of the occipital crest is indicated near the top of the picture. The notable narrowing, or postorbital constriction, is indicated near the center, beyond which are the great spaces available for the temporal muscles on each side.

The braincase was built from a core of plaster—a cast of an australopithecine skull of 510 cc—which was thickened somewhat to approximate a 600-cc capacity with a presumed vault thickness of 6–7 mm. This was placed between the mandibular condyles, about balanced in front and behind them, and elevated so that about one-tenth of its height was below the condyles' tops. This is the standard brain location in hominoids in relation to the condyles, with almost no variation.

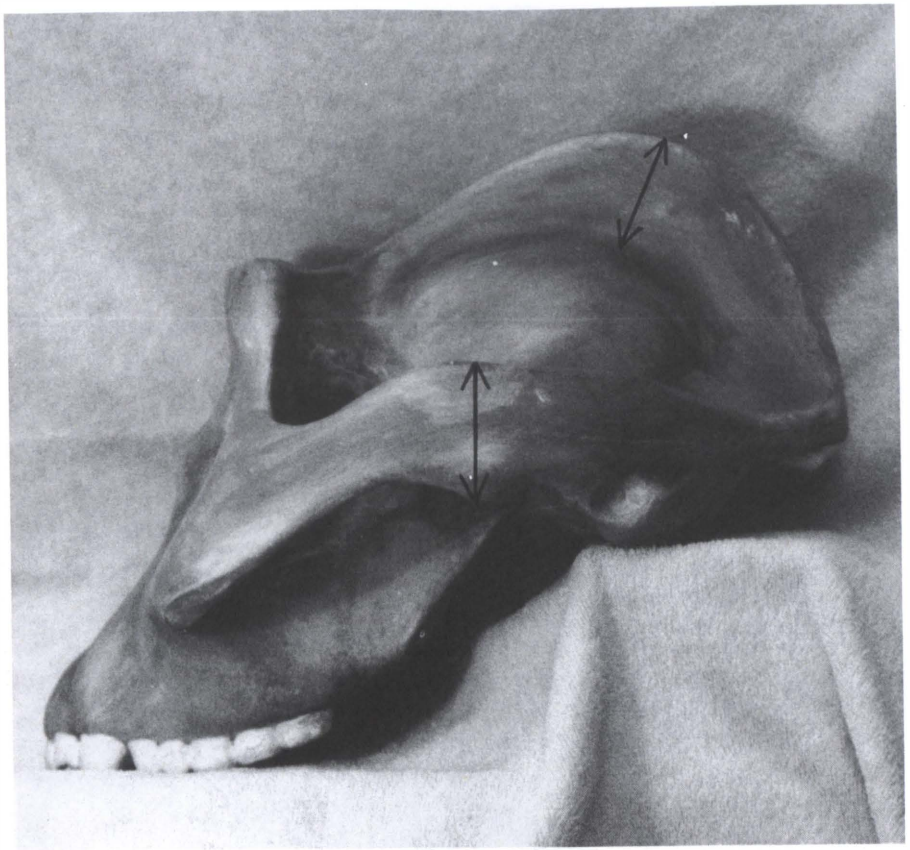

FIG. 5.—Side view of reconstructed cranium. The 50-mm extension of the sagittal crest is indicated near the top of the picture. Vertical thickening of the zygomatic arch is shown nearer the center.

From the sides of the braincase I built up typical mandibular sockets (glenoid fossae) that reached out and capped the condyles. From the lower front part I added material to join with the palate and growing nasal chamber that had already been constructed. This formed a basic frame upon which I could then add all other superstructures.

At the base of the braincase, from one jaw socket around the back to the other socket, I built a horizontal crest standing out about 30 mm (Fig. 4), and typically 15 mm thick (Fig. 6). This constitutes the supramastoid crest in each ear region, and the occipital crest across the back. The size of this crest was carefully calculated for leverage for the muscles of the neck that would have inserted below it in an erect body. The size and shape of this structure was further refined as the rest of the reconstruction progressed. If

this errs, I think it is on the conservative side; it could have been made more prominent.

Orbit size was extrapolated up from the gorilla, much as was done with brain volume. I made cones of plaster, gradually enlarging them until they looked about right—inside diameters at rims of 65 mm in both directions, and with depths also correspondingly greater than in the gorilla (Fig. 3). Their thickness, including brow ridges, was again scaled up from the gorilla as would appear to have been necessary to avoid breakage from rough handling in life. Considering the inertial mass that emerges, such bony strength would have to be very great. Again, I may have underestimated the strength of the structures involved.

The orbits had to be placed well forward of the cheeks in order for them to clear the coronoid processes of the mandible. The evidently vertical emplacement of the upper incisors and canines argued for a nearly vertical upper face, also putting the orbits well forward. Vertical placement of the orbits was roughly dictated by the nasal cavity that had already been built. At this level, the optic foramina would enter the braincase at the anatomically correct place. Again, there is internal cross-checking of the design.

Having built and placed the orbits in relation to other facial parts, I then found they were extraordinarily far forward from the braincase (Figs. 4 and 5). Likewise, the back of the upper jaw was also well ahead of the braincase, in addition to being placed far below it. In effect, the apparent joining of facial to cranial parts was reduced to remarkably slender connections. I therefore felt obliged to arbitrarily add extra thickening to much of this connecting area, and to introduce something of a diagonal brace from the lower front of the braincase to the back of the upper jaw. The position of this brace was determined for maximum strength and minimum interference with muscular actions in this area.

Still, the depression left between face and braincase remained impressive (see especially Fig. 4). The more modest development of this same depression in other skulls is known as the temporal fossa. It contains the anterior portion of the temporal, one of the major chewing muscles. It does not automatically follow that the fossa was entirely filled with temporal muscle; however, given the power needed to move a jaw of this size, such a large temporal muscle may well be expected.

The temporal muscles, in all mammals, originate on the sides of the braincase, pass forward and downward under the zygomatic arches, and insert in the coronoid processes of the mandible. In this case, as with the larger apes, the muscle is so large relative to the brain that it covers the braincase entirely and originates from a sagittal crest. This crest extends above and behind the braincase in the midline. Its prominence appears mainly to provide for length of action of this muscle rather than for area of attachment.

As a given type of animal is increased in size, jaw muscles increase in proportion to the total body, while the braincase increases only slightly. Smaller apes lack sagittal crests—the relatively large braincase providing sufficient attachment for the temporal muscles. Male orang-utans and female gorillas often have slight crests, while the male gorilla regularly shows a prominent one. The absolute size of both sexes of *Gigantopithecus* evidently exceeds the male gorilla, and would be expected to have correspondingly larger sagittal crests. In the reconstructed male specimen here, a crest standing 50 mm tall, twice that of the gorilla, is thus a reasonable expectation (Fig. 5).

In gorillas, the major projection of the crest is toward the rear of the braincase; in *Australopithecus,* when it occurs at all, it is more at the top of the skull. Given the hominid design of the skull being reconstructed, the upper emphasis might be expected (Tim White, personal communication). On the other hand, the recently discovered earliest example of *A. boisei* has a more posterior emphasis to the crest (Walker *et al.* 1986). I designed the *Gigantopithecus* crest, on the basis of an indefinable "feel," to have this same posterior emphasis. The accuracy of this detail remains uncertain.

Gross restoration of the zygomatic arches was simple. They arose above the first molar, as in most hominids, swung around well clear of the coronoid processes, and joined the base of the skull above the condyles and ears to merge into the occipital crest. Their thickness and height, at least anteriorally, posed no problem, though a somewhat greater size and lateral flare might have been added (Allan Smith, personal communication). The masseter muscles, running from the underside of this part of the arch down to the angle of the mandible, were evidently powerfully developed. This means that the arch itself must be strongly built to resist their downward pull.

Reconstructing the rear part of the zygomatic arch posed an unexpected problem when it was observed that the jaw sockets were much more widely spaced than the sides of the braincase. In chewing, a considerable force is exerted upward through the condyle and into its socket, and which must then be dissipated into the skull. In the human skull, the side wall of the braincase passes down just to the outside of this socket, and thus braces the socket against upward displacement. In the gorilla skull, the side wall of the braincase passes down just to the inside of this socket, and thus likewise braces the socket against upward strain. In the *Gigantopithecus* skull, the side wall of the ape-sized braincase passes down some distance medial to the inside edge of the wide-set condyle, thus affording almost no direct resistance against upward strain (Fig. 6). The occipital crest of the gorilla, passing upward and backward from the socket, adds considerably to its bracing. But in *Gigantopithecus,* the horizontal occipital crest offers almost no such bracing.

Some structural support for the jaw socket was achieved by thickening

FIG. 6.—Rear view of reconstructed skull. The 15-mm thickness of the projecting occipital crest is indicated on the right between the short arrows. On the left are shown the opposing forces of jaw pressure and cranial-wall resistance which conspicuously mismatch.

the lower braincase wall, and making it spread out widely just above the socket. This mass would presumably be lightened by pneumatizing the bone—a network of air cells within a mesh of internal boney struts. This supramastoid inflation could go up only a short distance without interfering with the line of action of part of the overlying temporal muscle. A similar thickening on the underside, behind the socket, amounted to a very large mastoid

process; but its stabilizing ability was limited. Perhaps mastoids should be even larger, as White (personal communication) has suggested he would have made them.

Seeing that more strength was probably required, I introduced considerable vertical thickening of the rear part of the zygomatic arch (Fig. 5). This allows upward force at the socket to be braced from above, and thus transmitted through the entire arch to the face, and to the rear of the skull as well. This design was modeled on that of the horse skull, which I found has the same discrepancy between the locations of the condyles and braincase walls, as well as a chewing mechanism that closely parallels hominids.

A few other cranial details had to be included for the sake of completeness, but these are of no great significance to evolution or taxonomy. The shape of the brow ridges and the scrap of horizontal forehead just behind them were copied much along gorilla lines. The major muscle insertions on the base of the occipital (neck attachment) were just roughed in according to the hominid pattern. The occipital condyles were located up high against the base of the skull for lack of any reason to draw them down, and also to afford the head the most stable positioning. Petrous bones, basioccipital, and pterygoid wings were all primitive hominid and only roughly indicated.

My construction technique differed between jaw and skull. The jaw was built up in five steps by modeling the parts in Sculpy, which was baked hard after each step. The original plaster jaw was oiled repeatedly to preserve it through these bakings, and it barely survived intact.

In building the skull, I made the jaw sockets of Sculpy, baked them, then glued them to the plaster braincase that was used as a core. The maxilla was made from a half-depth copy of the lower jaw, greatly thickened with more plaster, then carved down. Orbits were made by thickly coating plaster on the outside of a small plastic funnel, which was then removed. The rest of the skull construction involved a slow process of mixing small amounts of hydrocal plaster and adding it on, often incorporating suitably shaped plaster scraps. The final product was scraped and sandpapered until it approached perfection, or until I tired of it.

The skull and jaw were then molded in Silastic (silicone rubber), in two pieces each. Good plaster copies are now being made and distributed.

Discussion

I have taken all possible measurements of the finished reconstruction and compared these with the cast of a large male gorilla. Needless to say, *Gigantopithecus* far exceeds the gorilla in every measurement. In three heights and three breadths, the gorilla clustered tightly around 70 percent of this new reconstruction; in three lengths, the discrepancy was less, with the gorilla averaging just over 80 percent.

Wu (1962) gives some measurements of his jaw reconstruction based on the same male specimen. He adds an admittedly speculative total facial height, and I have calculated the mandible length from his photographs. With this information, we may compare the length, breadth, and height of these two reconstructions with the gorilla.

Measurement	Gorilla (mm)	Krantz (mm)	X-Gor.	Wu (mm)	X-Gor.
Mandibular length	184	208	1.130*	253	1.375*
Bigonial breadth	134	189	1.410*	200	1.493*
Condyle height	124	199	1.524	183	1.476
Facial height	178	255	1.432	320	1.798
Mean of two heights	—	—	1.478*	—	1.637*

Since there are two height measurements from quite different parts of the skull, these are here averaged so their total will be weighted equally with length and breadth. These total ratios, averaging length, breadth, and height (indicated by asterisks) make my reconstruction 1.339 times larger than the male gorilla, and Wu's 1.502 times larger. Whether these figures can be translated into statures or any other gross body dimensions is a matter of speculation.

The volumetric comparisons are found by multiplying the three lineal dimensions together. By this reasoning, my version of *Gigantopithecus* should have weighed 2.3546 times as much as the male gorilla; Wu's version should be 3.3145 times heavier. If the gorilla weighed 180 kg (396 lbs.), then my figures put *Gigantopithecus* at 424 kg (933 lbs.), while Wu's figures give it 597 kg (1,313 lbs).

These weights need not be taken as definitive estimates because *Gigantopithecus* and gorilla body builds are not necessarily the same. However, if one chooses to use a significantly different weight estimate, then some justification ought to be given for doing so. My own inclination is to use the 424 kg from my reconstruction as the probable male body weight. A relatively more elongated body would be expected in an erect biped as opposed to a knuckle-walker, thus lowering the estimate. On the other hand, the individual used here may be smaller than average, and some of my reconstructions may also be incorrectly small.

And what if Wu's reconstructed size is more accurate?

Most people who have viewed my reconstruction are in no position to compare it with the supposedly living Sasquatch in any knowledgeable way. Those who possess the technical expertise to appreciate the structure of a primate skull have not seen the living animal, and those who claim to have seen a living Sasquatch cannot well interpret their observations in terms of cranial anatomy.

One notable exception is Robert Titmus, a hunter and taxidermist of long experience who claims to have seen several Sasquatches, one of them in full-face and close-up. His opinion, after long study, is that my reconstruction has about the size and general form that he would expect to find in the skulls of the animals he saw. Titmus has one reservation—that the eyes of the animal he claims to have seen were considerably farther apart than my reconstruction would allow. My positioning was based on an expanded gorilla, and certainly could be in error. At the same time, Titmus' observation is from many years ago, and his recollection might not be accurate. There could also be a difference between *Gigantopithecus* and Sasquatch in this part of the anatomy.

Summary

The skull reconstructed here is not likely to be far from the actual condition of *Gigantopithecus blacki.* The jaws and teeth are firmly based on actual fossils, and indicate a hominoid primate with affinities more hominid than pongid. Erect posture and a 600-cc brain size are strongly indicated, and these dictate most of the remaining cranial morphology. The total size of the resulting skull would call for a body more than twice as big as that of a male gorilla. That a bipedal hominoid of gigantic size lived in China half a million years ago seems to be well established. Whether an animal of this description is alive today is obviously a different matter, but at least the possibility should be considered open.

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